SCIENCE@BERKELEY LAB

August 6, 2007

The BATT FabLab: Road to a Better Battery

Allan Chen, a_chen@lbl.gov

The better transportation battery—a battery for hybrid-electric and plug-in hybrid vehicles—needs to be lighter than today's battery, store more charge, and last through more charge-discharge cycles. Also, it needs to be safe, affordable, and compact enough to fit under the hood.

That's a tall order. Developing a better battery for vehicles requires a multipronged approach to research and development, that of the Department of Energy's BATT program: Batteries for Advanced Transportation Technologies. Berkeley Lab's Environmental Energy Technologies Division (EETD) assists DOE in managing BATT research, which takes place here and at other national labs, universities, and private companies.

At Berkeley Lab and the University of California at Berkeley, BATT research includes using nanoprobe diagnostics to study advanced battery materials and computer modeling to improve lithium-ion (Li-ion) battery chemistry. Li-ion batteries are of considerable interest because they are lightweight and store more charge per unit weight than those currently used in hybrid electric vehicles.

Besides understanding Li-ion chemistry, other crucial needs are learning the best ways to engineer and fabricate advanced Li-ion batteries and how to test them for performance. Berkeley Lab's cell analysis and testing lab, recently renamed the BATT FabLab (Fab for Fabrication), has been testing the performance of new materials in experimental batteries for several years.

Evolution of a FabLab

The FabLab tests new materials from BATT programs at Berkeley Lab and elsewhere; in the process researchers learn more about the fundamentals of battery performance. They are well versed in making new battery cells by combining experimental electrode materials designed for hybrid-electric vehicles, sealing the materials in water-tight packages, and measuring their performance.

"We want to understand the science and engineering of what it takes to make a high performance electrode," says EETD's Vince Battaglia, program manager in charge of the FabLab. "We also provide a reliable evaluation of new materials developed within the BATT program, using our optimized electrode designs."

With the lab's old equipment, researchers made test-cell pouches containing variations of the same experimental materials proposed for a given battery. They ran these pouches through a large number of charge-discharge cycles to see how well they kept their maximum charge, measured how long a battery would function before its capacity began to fade, and did other tests.

Now, with assistance and feedback from researchers who model new materials on computers, the BATT FabLab has supercharged itself with new equipment. One result is a sharper focus on improving electrode engineering. The recent equipment upgrade includes new glove boxes and new equipment for manufacturing small experimental test cells.

"All battery assembly work now takes place inside of glove boxes to keep out water, which is a real killer in lithium-ion batteries," says Battaglia. Water is limited to less than one part per million in the boxes' inert atmosphere; by contrast, the dry rooms in many battery manufacturing facilities limit water in air to 50 parts per million.

continued

The lab also has a hydraulic Klein cell machine, an automated device that combines the battery's electrodes and generates sealed battery cells reproducibly. Many battery labs manufacture cells using hand-cranked devices, resulting in cells that are inconsistent in size and composition. The Klein cell machine leads to more representative aging analysis because it accurately replicates water-tight cells.

BATT FabLab researcher Gao Liu prepares a battery for testing. Inside a glove box, which controls water infiltration, he compresses the electrodes for higher energy density and better electronic contact (left). The test cells are finished in watch-sized, commercial form in the Klein machine (right).

Challenges of the lithium-ion battery

Before lithium-ion batteries can be manufactured economically and meet performance requirements for hybrid vehicles, battery engineers have to learn to control the performance of the electrodes in Li-ion batteries. Measures of performance include a battery's lifetime, the number of charge-discharge cycles it can run through before degrading too much to operate, the total amount of charge it can store—which translates directly into vehicle range—and how much charge it can discharge per second—which translates into vehicle acceleration.

"Batteries are like small, self-contained chemical reactors," says Battaglia. "The entire system needs to be optimized to get the best performance from the battery."

How the electrode is constructed—including physical characteristics such as thickness and porosity, the size and volume of components, and their degree of mixing—all affect battery performance. The manufacturing process is also a factor. Electrodes are fabricated from a slurry of materials and are cast into a cohesive film using a polymer binder. One active compound currently under study is lithium iron phosphate (LiFePO4) with trace components including carbon. The viscosity of the slurry is important—a less than optimal distribution of conductive particles produces a less than optimal battery. Other factors that can degrade performance include contamination by water or carbon dioxide and chemical interactions within the battery system.

The battery lab, in partnership with researchers producing chemical models of advanced batteries, looks for solutions to all of these problems—and others too. Volume constraints are a key barrier to the introduction of high-energy batteries; reducing the amount of nonactive material increases energy density and helps reduce waste and manufacturing costs. So another concern of the battery lab, Battaglia says, is to see how much extraneous material can be removed from a battery without affecting optimal performance.

Benchmarking for better batteries

Researchers in the battery lab benchmark experimental materials by measuring, among other things, their surface area, particle size, and particle-size distribution. Knowing these characteristics allows the researcher to fine-tune composition. For example, carbon particles increase conductivity.

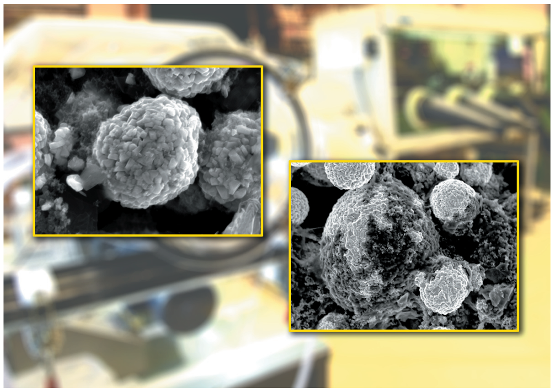
"When you get a sense of the size of particles in the electrode material, you can estimate what size of carbon particles to add to improve the material's electrochemical characteristics," Battaglia says.

The active material in the cathode (positive electrode) needs to be coated uniformly with carbon particles, then held together with a polymer binder. Poor carbon distribution can affect the battery's performance.

The battery lab also does thermal measurements of experimental cells. To its differential-thermal-analysis and accelerated-rate-calorimetry facilities it will soon add differential scanning calorimetry. By studying thermal properties researchers can find ways to prevent overheating, which can lead to battery fires.

The FabLab conducts electrochemical characterization of battery materials according to testing procedures like those established by the FreedomCAR program. A current problem for lithium-ion electrodes is their tendency to dissolve. Some researchers hypothesize that positive ions (cations) from the cathodes in these

continued



Better processing leads to better batteries. At left, broken particles of oxide in a lithium-iron-phosphate-based electrode show incomplete coating of carbon on their surfaces, which decreases electrode performance. At right, improved mixing of materials generates whole particles, better coated with conductive carbon.

chemical systems cause protective layers on the anodes to lose their protective capabilities. The dissolution of the protective layer leads to lithium depletion and eventual failure.

"We are trying to measure the rates of dissolution of the cathode materials outside the battery and correlate this to life estimates," says Battaglia.

Battery engineers try to avoid protective-layer dissolution by doping the cathode or coating it with stable Li-ion conductive films. New binders for the anodes may also limit the effect of the crossover of cations to the anode, protecting the anode and reducing passive film dissolution.

Lithium deposition on the anode during charging is another possible failure mode, especially during cold-temperature charging. Battery designers try to avoid this by using anodes with more capacity than the cathodes, but the anode's larger capacity can result in the battery having less overall cycling capacity, the ability to recharge over and over again after discharging, which reduces its lifetime. So engineers need to optimize the battery system as a whole to provide maximum protection to the anode without degrading battery lifetime.

Staying dry

Keeping water out of the battery system is a significant problem for battery engineers. Water can react to form positively charged protons, which rapidly degrade battery performance. Water in a lithium-ion battery reacts with a lithium salt to form an acid, which is thought to attack the cathode, causing its dissolution.

"We need to know how much water can get into the system before the performance begins to degrade," says Battaglia.

In the lab's glove boxes, Battaglia's research team manufactures test cells in an extremely low-humidity environment, then introduces water in higher and higher amounts. The researchers measure decrease in battery performance for different kinds of cells. Battery manufacturers, who need cost-effective ways to make batteries without letting in water, are extremely interested in this work. Process is half the cost of battery manufacture.

The BATT FabLab's research is multifaceted, but its goal is easy to summarize. Says Battaglia, "We are trying to understand why one battery material works better than another."

Additional information

More about BATT, DOE's multi-institutional Batteries for Advanced Transportation Technologies based at Berkeley Lab, is at http://eetd.lbl.gov/BERC/BATT/BATT.html.

More about the Berkeley Electrochemical Research Center at Berkeley Lab and UC Berkeley is at http://eetd.lbl.gov/BERC/BERC.html.

More about lithium-ion battery chemistry is at http://www.lbl.gov/Science-Articles/Archive/sabl/2007/Feb/future-batteries-I.html.

More about studying advanced battery materials with nanoprobe diagnostics is at http://www.lbl.gov/Science-Articles/Archive/sabl/2007/Feb/future-batteries-II.html.

More about previous programs for testing new materials for experimental batteries is at http://www.lbl.gov/Science-Articles/Archive/sb-EETD-better-batteries.html.